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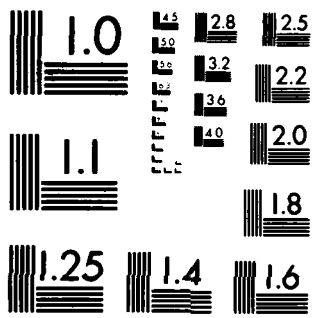

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Report 2402

COOPERATIVE PROGRAM EVALUATION OF NATO MULTIGRADED DIESEL ENGINE OILS

March 1984

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United States Army
Belvoir Research & Development Center
Fort Belvoir, Virginia 22060

Belvoir R&D Center

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The information contained in this report covers the United States portion of a cooperative NATO program investigating the performance characteristics of multigraded engine oil. Seven lubricants (one Grade 10W-30 oil, five Grade 15W-40 products, and a 20W-40 oil) were evaluated using the diesel engine performance tests required for qualification of MIL-L-2104D engine oils. Two test oils (one Grade 15W-40 product and the Grade 20W-40 oil) met the 1G2 four-cycle diesel performance established for MIL-L-2104D specification. Three products (two Grade 15W-40 lubricants and the Grade 20W-40 oil) demonstrated acceptable 6V53T, two-cycle diesel, performance. However, only the Grade 20W-40 oil showed acceptable performance in both tests.

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Based on the results of the program it was concluded that multigraded 15W-40 and 20W-40 oils have the capability to demonstrate acceptable diesel engine performance as defined by the MIL-L-2104D engine oil specification. In addition, it was established that meeting requirements for either two-cycle or four-cycle engine does not assure that a lubricant will demonstrate acceptable performance in both type engines. Therefore, lubricants specifications must include performance requirements for both two-cycle and four-cycle diesel engines.

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COOPERATIVE PROGRAM EVALUATION OF

NATO MULTIGRADED DIESEL ENGINE OILS

I. INTRODUCTION

1. Background. Replacement of single grade engine oils with lubricants requiring less frequent seasonal/climatic changes offer advantages for Military operation. Such multiseasonal or multigraded oils increase equipment readiness, improve lubricant utilization, and reduce maintenance and logistic-support requirements. For these reasons, there has been an increase in the use of multigraded engine oil within the NATO supply system. This has been manifested by the assignment of NATO Code Numbers for two lubricants: 0-1176 for a Grade 10W-30 oil intended for moderate duty and gasoline service and 0-236 for a Grade 15W-40 oil to be used in moderate duty diesel service.

The expanded use of multigraded products places emphasis on two factors: One, the compatibility of engine design with multigraded lubricants; and two, the capability of multigraded lubricants to exhibit acceptable performance in a wide variety of engine applications. These factors can be addressed by requiring that NATO type-testing of Military vehicle engines be conducted using a reference multigraded engine oil and by developing fully coordinated guide specification requirements for multigraded lubricants. Prior to the designation of a reference oil and establishment of guide or minimum specification requirements, it is necessary to evaluate the performance of these oils in a variety of engines. To accomplish this, a cooperative program was initiated under the NATO Military Agency for Standardization's Army Board to generate the necessary data for conducting these evaluations. The program consisted of investigating the performance characteristics of selected heavy-duty type multigraded oils supplied by different NATO countries and using the appropriate engine dynamometer test techniques specified by those NATO nations. The information contained in this report covers tests performed as the United States' portion of the cooperative program.

II. DETAILS OF TEST

2. Test Lubricants. Seven lubricants were selected for evaluation. Five oils denoted NATO-1 through -5 were provided by Norway (NO), France (FR), Germany (GE), Belgium (BE), and the United Kingdom (UK). The two remaining lubricants, designated US-1 and US-2, were supplied by the United States (US). The oils consisted of a Grade 10W-30 product, five Grade 15W-50 lubricants, and a Grade 20W-40 oil. Property data for the test lubricants are presented in Table 1. One of the 15W-40 oils, NATO-3 submitted by GE, is the Coordinating European Council's Reference oil designated as RL-82.

3. Test Techniques. Engine oils used in ground equipment operated by the US Military forces are supplied against the MIL-L-2104D specification requirements.[1] Although

[1] Military Specification, MIL-L-2104D, "Lubricating Oil, Internal Combustion Engine, Tactical Service," Government Printing Office, Washington, DC (April 83).

Table 1. Summary of Property Data for the Test Lubricants

Properties	Test Oil						
	NATO-1	NATO-2	NATO-3	NATO-4	NATO-5	US-1	US-2
Grade	10W-30	20W-40	15W-40	15W-40	15W-40	15W-40	15W-40
Submitted By	NO	FR	GE	BE	UK	US	US
Viscosity							(cSt)
@100° C	11.77	14.97	14.03	14.33	14.87	14.80	13.18
@40° C	76.1	123.1	94.1	103.9	110.0	112.8	96.9
Viscosity Index							
Flash Point (°C)	218	241	217	218	231	210	216
Total Acid Number	1.85	1.9	1.4	3.1	3.7	1.9	3.4
Total Base Number	6.54	7.8	8.4	11.0	9.5	8.2	12.5
Sulfated Ash (%M)	0.91	1.08	1.26	1.40	1.08	1.00	1.83
Elemental (%M)							
Calcium	0.21	0.18	0.33	0.39	0.30	0.10	0.49
Magnesium	Nil	0.06	Nil	Nil	Nil	0.10	Nil
Zinc	0.10	0.11	0.11	0.11	0.12	0.12	0.10
Phosphorus	0.09	0.09	0.11	0.09	0.11	0.11	0.14
Sulfur	1.12	1.13	0.71	0.58	0.82		0.59
Nitrogen	0.05	0.05	0.06	0.06	0.07	0.13	0.04
Boiling Point Distribution (°C)							
@1 Percent Pt	315	340	317	332	354	309	339
@5 Percent Pt	350	383	364	376	386	359	377
@10 Percent Pt	367	404	375	395	398	384	391
@20 Percent Pt	389	428	392	416	410	412	407
@30 Percent Pt	404	442	406	430	420	431	419
@40 Percent Pt	416	452	419	442	430	446	432
@50 Percent Pt	428	462	432	455	439	460	445
@60 Percent Pt	440	471	446	472	450	476	459
@70 Percent Pt	453	482	461	498	466	496	478
@80 Percent Pt	471	496	482	555	494	530	512
@90 Percent Pt	514	522			548	600	600
Residue (%M @ 600° C)	7.9	7.1	11.9	18.6	8.0	NA*	15.0

*Not available.

MIL-L-2104D establishes minimal property requirements for an oil, major emphasis is placed on lubricant performance as defined by a series of standardized, gasoline and diesel engine, dynamometer test techniques. These procedures are considered a natural starting point to form a basis for evaluating lubricant performance. Since the US tactical and combat fleets are predominately diesel powered, the two MIL-L-2104D diesel test techniques were selected for use in the cooperative program.

The first procedure selected was the Caterpillar 1G2 test[2] which addresses lubricant performance in four-cycle diesel engines. This procedure has been used in previous Military Specifications[3] as well as the MIL-L-2104D and commercial API/SAE CD oil classification.[4] The 1G2 performance requirements which have been established for MIL-L-2104D and commercial API/SAE CD engine oils are shown in Table 2.

This test procedure is also specified as one of the performance requirements in the Guide Specification for Heavy-Duty Engine Oils under STANAG 2845.

The second procedure used in the program was Federal Test Method 355T.[5] The test employs a cast-iron block Detroit Diesel 6V53T two-cycle diesel engine operated for 240 hours under cyclic conditions. The procedure was based on an endurance cycle developed by the US Army with assistance from the Coordinating Research Council (CRC). The Army/CRC cycle was intended for use in determining total engine-fuel-lubricant system compatibility and had been correlated with 4,000-mile proving ground operation of US Army tracked combat vehicles.[6] It was used in conjunction with various engines for evaluating MIL-L-2104B oils, and when MIL-L-2104C products were introduced, it was employed with the Teledyne-Continental AVDS-1790 and Detroit Diesel aluminum block 6V53T engines for evaluating these lubricants.

Based on past experience, the endurance cycle and the Detroit Diesel 6V53T engine were selected for investigating the use of multigraded oils in US Military equipment powered by two-cycle diesel engines[7,8,9] as this reflected the more severe environment for these oils. As a result of the multigraded oil program, the test technique was standardized, placed in Federal Test Method Standard (FTM) format and issued as Method No. FTM-335T. The procedure is now being used to define two-cycle diesel performance of MIL-L-2104D engine oils. The established performance criteria for the 6V53T procedure are presented in Table 3.

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2 "Single Cylinder Engine Tests for Evaluating the Performance of Crankcase Lubricants, Part I; Catepillar 1G2 Test Method," Special Technical Publication 509A, American Society for Testing and Materials, Philadelphia, PA (1979).

3 Military Specification, MIL-L-2104C, "Lubricating Oil, Internal Combustion Engine, Tactical Service, Amendment 1," Government Printing Office, Washington, DC (Aug 78).

4 "Engine Oil Performance and Engine Service Classification-SAE J183 FEB 80," 1983 SAE Handbook, Society of Automotive Engineers, Warrendale, PA (1983).

5 "Method 355T, Performance of Engine Lubricating Oils in a Two-Cycle Diesel Engine Under Cyclic, Turbo-Supercharged Conditions," Federal Test Method Standard 791C *(in preparation)*.

6 Development of Military Fuel/Lubricant/Engine Compatibility Test," Coordinating Research Council, Inc., Atlanta, GA (Jan 67).

7 Lesta, S.J.; Bowen, T.C.; and LePera, M.E.; "Fuel and Lubricant Compatibility Studies for Army High-Output, Two-Cycle Diesel Engines," Intern Report AFLRL No. 80, AD A031885, National Technical Information Service, Springfield, VA (Sep 76).

8 Moon, R. B. and Montemayor, A.F., "Laboratory Evaluation of Multiviscosity Grade Engine Oils in US Army Diesel Engines," Interim Report AFLRL No. 112, AD A108890, National Technical Information Service, Springfield, VA (Sep 81).

9 Montemayor, A. F.; Owens, E. C.; Frame, E. A.; Lesta, S. J.; and Bowen, T. C.; "Laboratory Evaluation of Army Multiviscosity Grade Tactical Engine Oils," SAE Paper 831719, Society of Automotive Engineers, Warrendale, PA (Nov 83)

Table 2. Caterpillar 1G2 Test Requirements for MIL-L-2104D and Commercial API/SAE CD Quality Engine Oils

Performance Criteria	Requirement
Top Groove Carbon Filling (percent vol max)	80
Weighted Total Demerits (max)	300
Ring Side Clearance Loss (in max)	0.0005

Table 3. Detroit Diesel 6V53T (FTM-355T) Test Requirements for MIL-L-2104D Engine Oils

Performance Criteria	Requirement
Piston Area	
Average Total Deposits (max)	400
Hot Stuck Rings	None
Average Ring Face Distress (max)	
Fire Ring	Report
Nos. 2 and 3 Compression	13.0
Liner and Head Area	
Average Liner Scuffing (percent max)	12.0
Valve Distress	None
Port Plugging (percent)	Report

An abridged version of the procedure is provided in Appendix A.

4. Conduct of Tests. The Caterpillar 1G2 tests were conducted using the facilities of Southwest Research Institute, San Antonio, Texas. All tests were conducted on installations calibrated under the American Society For Testing and Material (ASTM) monitoring program and which were approved for conducting the US Military lubricant qualification tests. Since test stands were calibrated, there was no need to conduct reference oil tests during the program. The Detroit Diesel 6V453T tests were performed by the US Army Fuels and Lubricants Research Laboratory, San Antonio, Texas. The facilities were the same ones used for development of the FTM-355T procedure and used in the investigation of multigraded engine oils for inclusion in US Military engine oil specifications. Again, the installation was calibrated avoiding the necessity to conduct reference tests as part of the program. Tests were performed as indicated by Table 4.

5. Caterpillar 1G2 Tests. Caterpillar 1G2 test results for the test oils and ASTM calibration data for reference oil REO-203 are summarized in Table 5. Included for the test lubricants are ratings conducted by the testing laboratory and a deposit rating performed by a referee rater. The deposit data are also shown graphically in Figure 1. Data analysis for deposits is based on the referee rating. The data show the test oils to range from 61 to 96 percent Top Groove Filling (TGF) and 228 to 493 Weighted Total Demerits (WTD). Of the lubricants tested, two oils—NATO-2 (FR) and US-2—conform with MIL-L-2104D 1G2 testing requirements. The remaining oils—NATO-1 (NO), NATO-3 (GE), NATO-4 (BE), NATO-5 (UK), and US-1—were in excess of the 80 percent Top Groove Carbon Filling and 300 Weighted Total Demerits values established by the specification.

6. 6V53T Tests. Federal Test Method 355T test results for the test oils and REO-203 reference oil are summarized in Table 6 and presented graphically in Figure 2. During the course of the test program, several changes were made in rating procedures. Originally, ring distress was defined as the percent area of the ring face affected or exhibiting distress. This was revised to a demerit number which weights the area covered by a factor based on the type of distress (pitting, burning, etc.) and severity (heavy, medium, etc.) observed. Also, an average of the five least-severe cylinders was used to eliminate bounce induced from the high severity observed for individual, single-cylinder assemblies. In addition to the rating change, tests on oils NATO-1 (NO), NATO-2 (FR), and NATO-3 (GE) were conducted with higher tension, upper, oil-control, ring expanders. As can be seen from Table 7, the higher tension expanders significantly increased test severity.

Subsequently, arrangements were made with the engine manufacturer to furnish lower tension expanders, and the test procedure has been modified to require the use of expanders falling within a specified tension range. All test data presented in Table 6 were adjusted to conform with current rating procedures and the use of low-tension expanders. Procedures used in making adjustments are described in Appendix B.

Table 4. Dates for Caterpillar 1G2 and FTM-355T Tests

	Date of Performance	
Test Oil	Caterpillar 1G2 Test	FTM-355T Test
NATO-1	Nov 81	Nov 81
NATO-2	Nov 81	Dec 81
NATO-3	Dec 81	Jan 82
NATO-4	Nov 82	Aug 82
NATO-5	Oct 83	Jul 83
US-1	Feb 82	May 80*
US-2	Sep 82	Sep 82

*Conducted as a portion of multigraded oil investigation.

Table 5. Summary of Caterpillar 1G2 Test Results and REO-203 Reference Data

Parameter	REO-203*	NATO-1 (NO)	NATO-2 (FR)	NATO-3 (GE)	NATO-4 (BE)	NATO-5 (UK)	US-1	US-2
		Test Oil						
Laboratory Rating								
Top Groove Carbon Filling (percent vol)	—	83	58	98	61	67	63	60
Weighted Total Demerits	—	526	232	376	455	487	453	228
Ring Side Clearance Loss	—	0.0000	0.0000	0.0000	-0.0005	-0.0005	0.0000	0.0000
Referee Rating								
Top Groove Carbon Filling (percent vol)	67	75	58	96	67	61	57	58
Weighted Total Deriierits	183	466	228	330	489	493	400	260

*Average of 243 ASTM calibration tests.

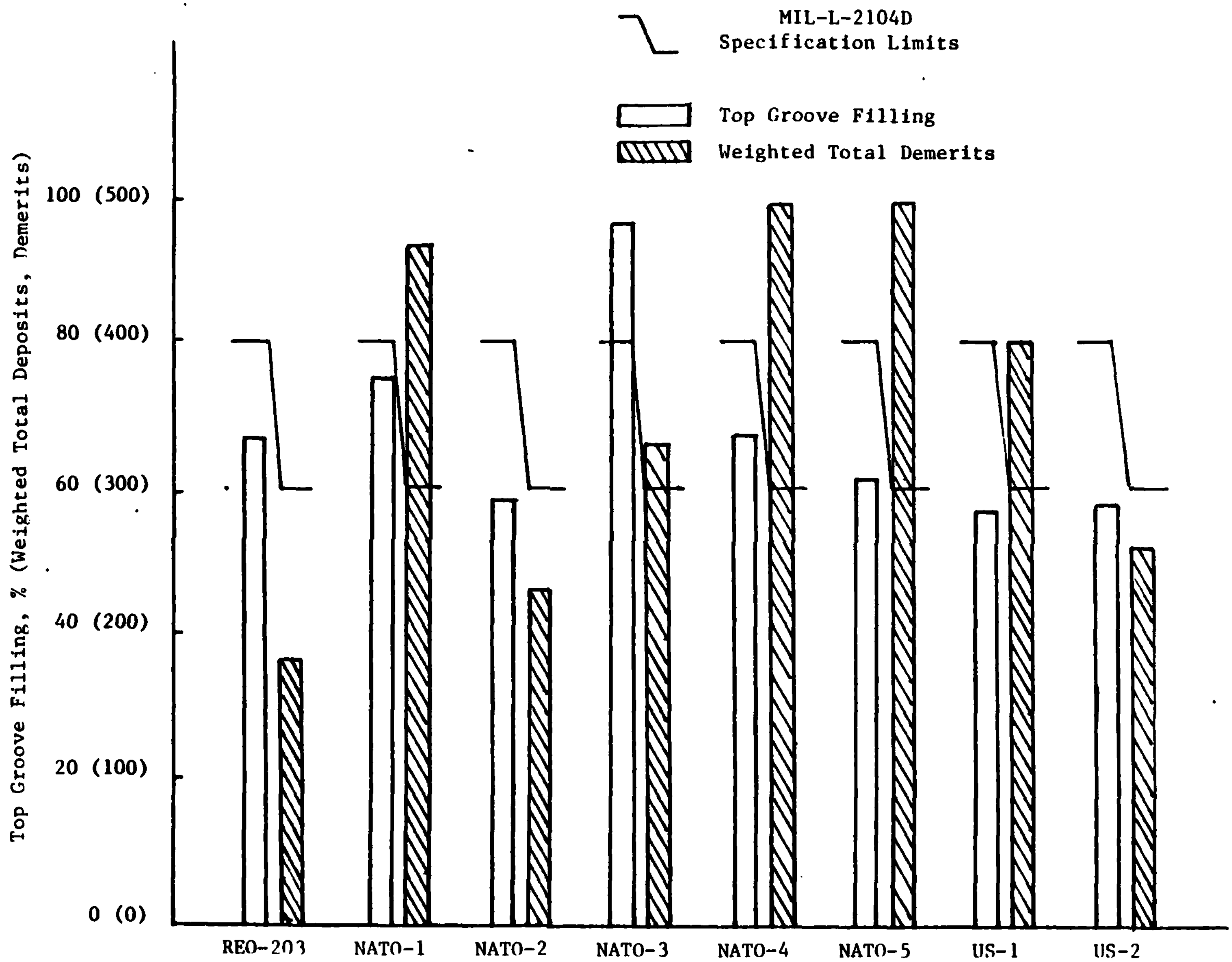

Figure 1. Summary of Caterpillar 1G2 deposit results for test oils and REO-203 reference oil.

Table 6. Summary of Detroit Diesel 6V53T Test Results and REO-203 Reference Data

Parameter	Test Oil							
	REO-203*	NATO-1	NATO-2	NATO-3	NATO-4	NATO-5	US-1	US-2
Piston Area								
Average Total Deposits (demerits)	256	329	329	305	248	260	362	240
Hot Stuck Rings	0	4	0	0	0	0	0	0
Average Rings Distress (demerits)								
Fire Ring	7.1	15.2	2.0	4.2	24.9	24.4	0.5	41.9
Nos. 2 and 3 Compression	8.2	12.8	3.7	6.7	15.9	25.9	1.1	44.4
Liner and Head Area								
Average Liner Scuffing (percent)	8.5	12.2	4.6	3.2	7.6	26.1	5.9	53.0
Valve Distress	0	0	0	0	0	0	0	0
Port Plugging (percent)	1	4.6	1	7.8	1	1	1	1
Hours of Test	240	46.5	240	240	240	240	240	200

*Average data for 29 calibration tests.

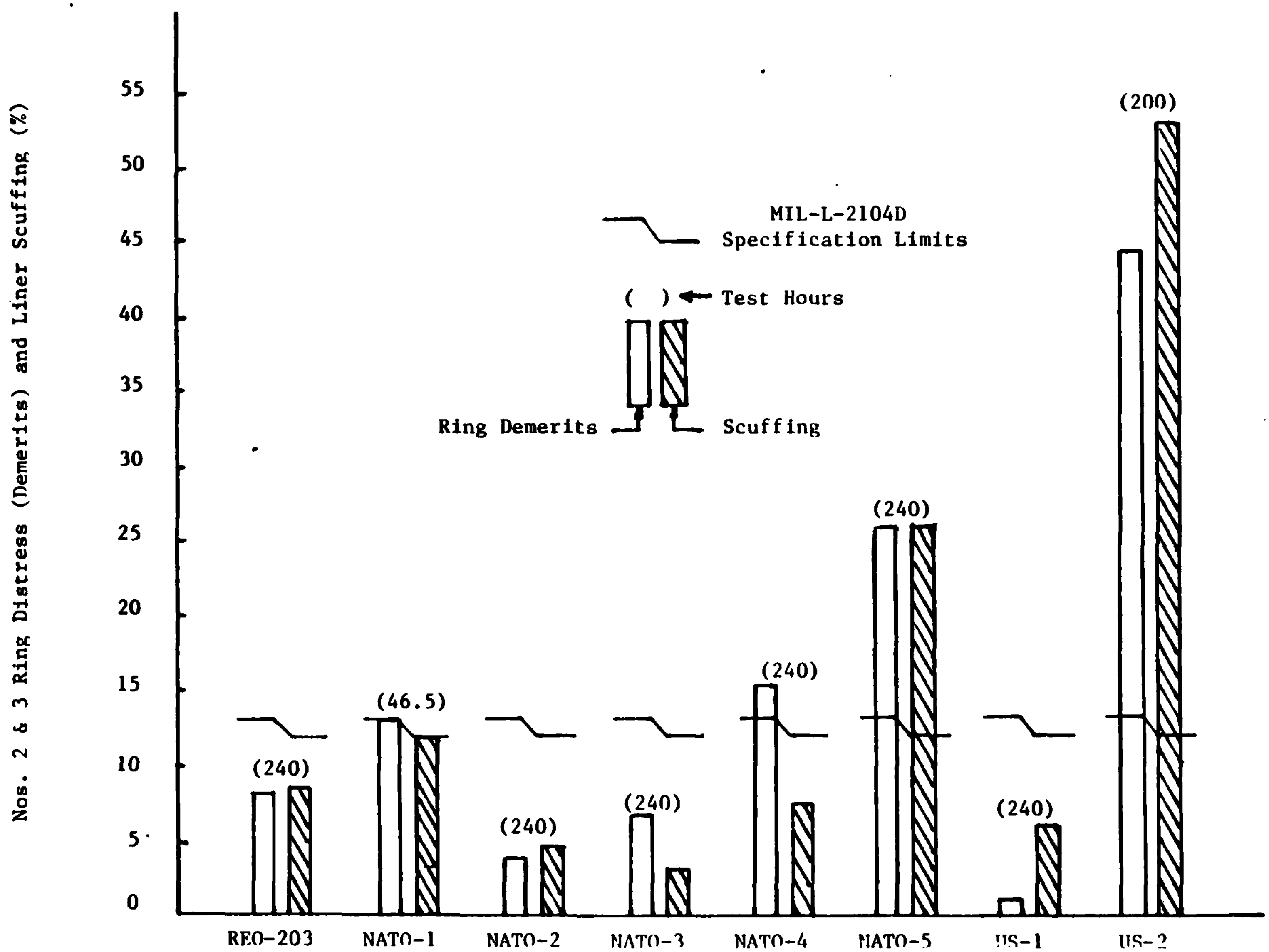

Figure 2. Summary of Detroit diesel 6V53T ring distress and liner scuffing results for test oils and REO-203 reference oil.

Table 7. Average Ring Distress and Liner Scuffing Ratings for REO-203 Calibration Tests Using Low- and High-Tension Expanders

Parameter	Average Ratings	
	Low-Tension Expanders	High-Tension Expanders
Number of Tests	7	11
Nos. 2 and 3 Ring Distress (percent)	8.1	25.6
Liner Scuffing (percent)	5.6	18.2

Of the lubricants tested, three oils—NATO-2 (FR), NATO-3 (GE), and US-1—met MIL-L-2104D requirements. Three oils—NATO-1 (NO), NATO-5 (UK), and US-2—exhibited unacceptable performance not meeting specification requirements. In fact, tests on two of these lubricants—NATO-1 and US-2—were stopped prior to completion of the full 240-hour operation because of high wear metals in the used oil and high engine blowby. The remaining oil—NATO-4 (BE)—met the scuffing requirements but marginally failed the ring distress criterion.

7. **Performance Summary.** Table 8 provides a summary of test oil performance in relationship to requirements established for MIL-L-2104D.

As can be seen, one oil—NATO-2 (FR)—was judged acceptable, passing the requirements for both test techniques. The remaining test oils were judged unacceptable as formulated.

Table 8. Summary of Lubricant Performance in Relationship to MIL-L-2104D Diesel Requirements

	Test Oil						
Test Oil	NATO-1	NATO-2	NATO-3	NATO-4	NATO-5	US-1	US-2
Caterpillar 1G2	U	A	U	U	U	U	A
Detroit Diesel 6V53T	U	A	A	BL	U	A	U
Overall Rating	U	A	U	U	U	U	U

A = Acceptable
U = Unacceptable
BL = Borderline

III. CONCLUSIONS

8. The following conclusions are based on the results of the test program:

a. There are multigraded oils within the NATO system that exhibit acceptable performance in diesel engines as defined by the MIL-L-2104D test techniques.

b. Meeting requirements for either the four-cycle diesel or the two-cycle diesel does not assure that a lubricant will provide acceptable performance in both types of engines.

c. Both Grade 15W-40 and Grade 20W-40 oils can perform satisfactorily in diesel-powered equipment.

d. None of the Grade 15W-40 lubricants tested demonstrated acceptable performance for use as a reference oil in NATO-type engine testing.

e. A NATO guide specification for multigraded engine oils must establish performance requirements for both two-cycle and four-cycle diesel engines.

APPENDIX A

DETROIT DIESEL 6V53T (FTM-355T) TEST PROCEDURE (ABRIDGED)

I. SCOPE AND SUMMARY

This method is used for determining the effect of lubricating oils on wear, ring-sticking, and accumulation of deposits in a reciprocating internal combustion engine. Evaluation is based on: (a) the ability of the test engine to maintain performance throughout the cycle; (b) wear of critical engine components; (c) accumulation of fuel and lubricant related engine deposits, particularly in the piston ring zone areas; and (d) the physical and chemical condition of the lubricant monitored throughout the test.

The test involves the operation of a militarized 6-cylinder, fuel-injected, turbo-supercharged, 2-stroke-cycle diesel engine under cyclic conditions for a total of 240 hours. Prior to test the engine is reconditioned as described herein. Evaluation is made by comparing the test oil performance with that of a reference oil of known quality.

II. ENGINE BUILDUP AND RUN-IN

A. Engine Buildup. The engine is rebuilt with new cylinder kits (pistons, rings, liners, and piston pins). Other parts (rods, bearings, etc.) are checked against specified tolerances and replaced as warranted.

B. Engine Run-In. A run-in is conducted with Grade 30 reference oil (REO-203) under the following conditions:

Speed (r/min)	Load (lb-ft)	bhp Obs.	Time (min)
1800	88	30	15
2200	310	130	30
2500	420	200	30
2800	422	225	30

C. Power Check and Shake-Down Run. An initial power check is performed at full-rack power and at 2200, 2500, and 2800 r/min. A 5-hour shake-down run at 2800 r/min and 250 bhp is conducted followed by a final full-rack power check at 2200, 2500, and 2800 r/min.

III. OIL TEST SECTION

A. Oil Flush. Test oil is installed and the engine operated for 30 minutes. The initial charge is removed and fresh test oil is installed.

B. Full-Load Performance. Full-load performance is determined at 200-r/min intervals between engine speeds of 1800 and 2800 r/min.

C. Test Cycle. The engine is operated under the following cycle and conditions for a total of 240 hours of engine operation.

Endurance Test Operating Cycle

Period	Mode	Time (h)	Load (percent)	Speed (r/min)	Jacket-Out Temp (°F)
1	Idle	0.5	0	675 ± 10	100
	Max Power	2	100	2800 ± 10	170
	Idle	9.5	0	675 ± 10	100
	Max Torque	2	100	2200 ± 10	170
2	Idle	0.5	0	675	100
	Max Power	2	100	2800	170
	Idle	0.5	0	675	100
	Max Torque	2	100	200	170
3	Idle	0.5	0	675	100
	Max Power	2	100	2800	170
	Idle	0.5	0	675	100
	Max Torque	2	100	2200	170
4	0.5	0	675	100	
	Max Power	2	100	2800	170
	Idle	0.5	0	675	100
	Max Torque	2	100	2200	170
5	Shutdown	4	0	0	

Operating Condition	Limits		
	Max Power Mode	Max Torque Mode	Idle Mode
Speed (r/min)	2800 ± 10	2200 ± 10	675 ± 10
Fuel Flow—Typical, Net Btu/h	2,421,000 max	2,054,300 max	—
Obs bhp Output	300 ± 5	265 ± 5	100 ± 2
Jacket-out (°F)	170 ± 2	170 ± 2	100 ± 2
Coolant T (°F)	8—12	8—12	2—3
Oil Sump (°F)	250 max	250 max	—
Fuel Temp at Filter	90 ± 5	90± 5	—
Fuel Pressure (range)	35—70	35—70	35—70
Compressor Suction, clean filter (in. water)	8.0 max		
Compressor Suction, dirty filter (in. water)	10.0 max		
Exhaust Back Pressure (after turbo)(in. Hg max)	2.7	2.1	
Blowby Pressure (in. water)	4.0 max*		
Oil Pressure (lb/in.^{2})	30 min	30 min	5 min

*Blowby pressure greater than 4 in. of water constitutes test shutdown for inspection.

Operation	0	20	40	60	80	100	120	140	160	180	200	220	240
Oil Adjustments	–	X	X	X	X	X	X	X	X	X	X	X	–
Oil Sampled	X	X	–	X	–	–	X	–	–	X	–	–	X
Airbox Inspected	X	–	–	X	–	–	X	–	–	X	–	–	–
Oil Change	X	–	–	–	–	–	X	–	–	–	–	–	–

D. Full-Load Performance. Full-load performance is determined at 200-r/min intervals between engine speeds of 180 and 2800 r/min.

IV. POST TEST SECTION

A. Piston Ratings. Using the terminology of D, the CRC Diesel Engine Rating Manual No. 5, and the proposed CRC Rating System for Diesel Engine Deposits (First Draft), rate the pistons for the following:

Ring groove carbon filling, percent ring supporting carbon, and Weighted Total Demerit (WTD).
Skirt lacquer.
Ring sticking.
Oil Control Ring Groove Lacquer.
Ring Face Condition.

B. Cylinder Liner Ratings. Using the terminology of D and CRC Diesel Engine Rating Manual No. 5, rate the cylinder liners for the following:

Intake Port Restriction.
Scuffing (percent fire ring travel area).
Glazing (percent fire ring travel area).

C. Other Ratings. Combustion chamber deposits in the cylinder had and in the piston crowns shall be rated in terms of texture and depth. Exhaust valves, camshaft lobs, rocker arms, tappets/roller-followers, exhaust valve bridges, crankshaft journals, and main/connecting rod bearing inserts will also be rated.

D. Rating Terminology. Ratings shall be made using the CRC Diesel Engine Rating Manual No. 5 and terminology defined as follows:

Scuffing—Mechanical disturbance of a rubbing substance with no appreciable surface roughness to feel.

Scoring—Mechanical disturbance of a rubbing surface with a definite surface roughness in line with motion characterized by the transfer of metal by dragging which results in progressive deterioration.

Seizure—Sticking together of two surfaces characterized by the presence of small particles of material which have become welded to the surface.

Glazing—Continuous removal of surface material resulting in a mirror-polished appearance of very low micro-finish.

Burning—Removal of metal from sealing surface (ring face) to form leakage paths.

Lacquer—A thin varnish-like deposit which cannot be removed by wiping with saturated solvents, such as petroleum naphtha, but is soluble in lacquer solvents, such as benzene and acetone.

Carbon—A firm deposit composed primarily of hydrocarbon residue which has thickness, volume, and texture (hard, medium, and soft).

Ash—Residue of combustion, inorganic in nature.

Ring Sticking—The relative degree of freedom of a piston ring in its groove as removed from the engine.

APPENDIX B

PROCEDURES FOR ADJUSTING DETROIT DIESEL 6V53T RATINGS

To Adjust from High- to Low-Tension Expanders:

Ratios of Low-Tension:High-Tension Tests were established using REO-203 calibration data. The ratios were as follows:

$$\text{For Ring Distress} \quad \frac{8.1}{25.6} \quad \text{or } 0.316{:}1$$

$$\text{For Liner Scuffing} \quad \frac{5.6}{18.2} \quad \text{or } 0.3081$$

The adjusted value was determined using the following equation:

$$\text{Adjusted Result} = (\text{High-Tension Result})(\text{Ratio})$$

Note that piston deposits remained constant.

To Adjust from Initial Distress and Scuffing to Revised Rating Method:

The results of 18 tests were used to establish the following linear regression correlations between ratings:

$$\text{For Ring Distress: } Y = 0.4859X - 3.793,\ R2 = 0.8339$$

$$\text{For Liner Scuffing: } Y = 0.8225X - 4.7818,\ R2 = 0.9299$$

Where: Y = Adjusted Result
X = Initial Rating

It should be noted that no adjustments were made where test parts were retained: rather, the parts were rerated using the revised procedure.

Summary of Adjustments

Test Oil	Expander Tension	Revised Rating	No Adjustment
NATO-1	X	—	—
NATO-2	X	—	—
NATO-3	X	—	—
NATO-4	—	—	—
NATO-5	—	—	
US-1	X	X	—
US-2	—	—	X

X = Type adjustment used.

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